CHAPTER D.4
WAVE AND STORM PROTECTION PROVIDED BY LOUISIANA'S GULF SHORELINE: BARRIER ISLANDS AND SHELL REEFS

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4.1 Summary

This chapter describes how barrier islands and shell reefs protect Louisiana's wetlands. Modeling studies have shown that as Louisiana's barrier islands and shell reefs disappear, once protected inland bays are experiencing substantially higher waves and storm surges. These water conditions resemble those of the open sea, and they threaten the entire inland estuarine ecosystem. Restoration of the coast is thus an essential step for the long-term health of south Louisiana.

4.2 Barrier Islands

4.2.1 Introduction

The importance of barrier islands in protecting the bays and fringing bay marshes is clearly evident along the Louisiana coast. Barrier islands very effectively reduce the wave and surge field during tropical cyclones, winter storms, and fair-weather wave conditions. The data presented to date show conclusively that: (1.) the bays in south central Louisiana have gradually transformed into higher energy marine environments, and (2.) marshes fringing the bays have experienced increased erosion due to waves. In the absence of large scale barrier restoration, wave forecasts indicate that this transformation will likely accelerate. With the beginning of every new hurricane season, coastal Louisiana, once significantly protected by the barrier islands, becomes more vulnerable to storm wave and storm surge inundation.

A considerable amount of work has been conducted to establish the effects of hurricanes and tropical storms on coastal Louisiana (Penland et al. 1989; Stone et al. 1993; 1996; 1997;

1999; 2003). It is now reasonably well established that because of the gradual demise of barrier islands along south-central Louisiana, wave energy conditions in the bays are increasing with time (Stone and McBride 1998; Stone et al. 2003). This phenomenon is apparent during fair-weather wave conditions and during storms when lower frequency waves propagate through wider inlets and breaches along the barrier system.

4.2.2 Numerical Wave Modeling

A numerical wave modeling study (Stone and McBride 1998) shows a clear positive correlation between barrier loss and increases in bay wave energy. Forecasts of barrier island loss (Isles Dernieres and Timbalier Islands) from the 1990s through 2020 show dramatic increases in bay wave energy with time even when simulating fairweather (mild) wave energy conditions. An example of these results is presented in Figure D.4- 1. Most notable is the projected loss of barrier islands (assuming no restoration is undertaken) between 2020 and 2050. The resultant increase in bay wave energy is dramatic.

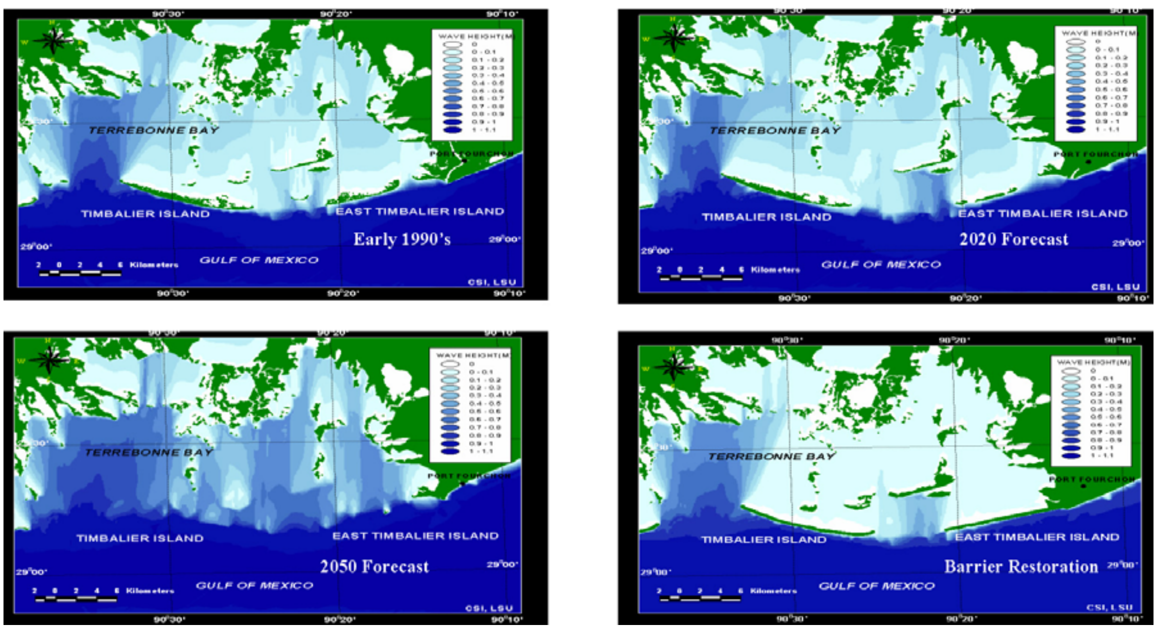


Figure D.4- 1. Numerically derived wave field under fairweather, deep water wave conditions along the Timbalier islands and Fourchon. Note increase in wave height behind the barriers with time as the barrier system erodes. The simulated restored barriers demonstrate the importance of barrier islands in reducing wave energy in these bays and, therefore, marsh protection (from Stone et al. 2003)

The importance of barrier island restoration is also evident when a hypothetical barrier system is included in the numerical approach, and a dramatic decrease in wave energy in the bays occurs. These data support the contention that if the outer coast is not restored, presently protected bay systems will be rapidly transformed into open marine conditions. Thus, marsh shorelines fringing these bays will continue to experience higher wave energy levels, since these waves no longer break along the Gulf-facing beaches but propagate shoreward and dissipate their energy along the marsh shorelines.

4.2.3 Extreme Events

Although fair weather waves are becoming increasingly efficient at eroding bay flanking marshes, erosion rates are considerably more pronounced during tropical storms and hurricanes. In 2002, south-central Louisiana was impacted by Tropical Storm Isidore and Hurricane Lili; two other tropical cyclones impacted the area during that year as well. The track of Isidore is shown in Figure D.4- 2 as it moved over land between Grand Isle and East Timbalier Island. Wave heights accompanying this storm are shown in Figure D.4- 3 for four stations extending from the central Gulf (NDBC 42001 and 42041) to shallow water (CSI 6 and 5) fronting Timbalier Island and a fifth station (CSI 11) in the protected waters of Terrebonne Bay immediately behind the island. As these waves moved into shallower water, their energy dissipated due to bottom interaction as the wave height decreased. The effect of Timbalier Island on reducing wave energy, however, is clearly apparent, and the resultant wave heights in Terrebonne Bay are significantly reduced when compared to waves in the open Gulf. These measurements further support the numerical wave studies discussed earlier.

4.2.4 The Significance of Storm Surge

The relationship between storm surge and the morphological integrity of the barrier islands is also very important. Precise surge elevations were recorded during Isidore and Lili and are shown on Figure D.4- 4 for CSI 5 and CSI 11. Surge levels were slightly higher in Terrebonne Bay when compared to the offshore station. As the barrier islands decrease in size with time, local observations indicate that less powerful storms are generating storm surge levels in the bays and along the bay shorelines which are comparable in size to past, more powerful storm systems. Although there are no scientific measurements to support this statement, the results of a recent study (Stone et al. 2003) do shed some light on this issue and are described in more detail below.

The primary objective of this pilot study was to evaluate, using state-of-the-art numerical hydrodynamics models, how the loss of barrier islands and wetlands affects storm surge and wave energy along a portion of the south-central Louisiana coast. The area selected for the study included the Isles Dernieres, Timbaliers, and east to the Caminada Moreau Headland as shown in Figure D.4- 5. The left image in this figure shows the area of land as of 1950. The central panel shows the area in the early 1990s and the right panel is a forecast of the study site for the year 2020. Using a Hurricane Planetary Boundary model, a storm surge model (ADCIRC) and wave model (SWAN), storm surge and wave fields were modeled for a category three hurricane that made impact along the area in 1915. The true track of the storm was moved to the west (see track on figure) in an attempt to maximize the wind, surge, and wave field in the study area. Simulations were undertaken for the three time periods mentioned, and the resultant data compared.

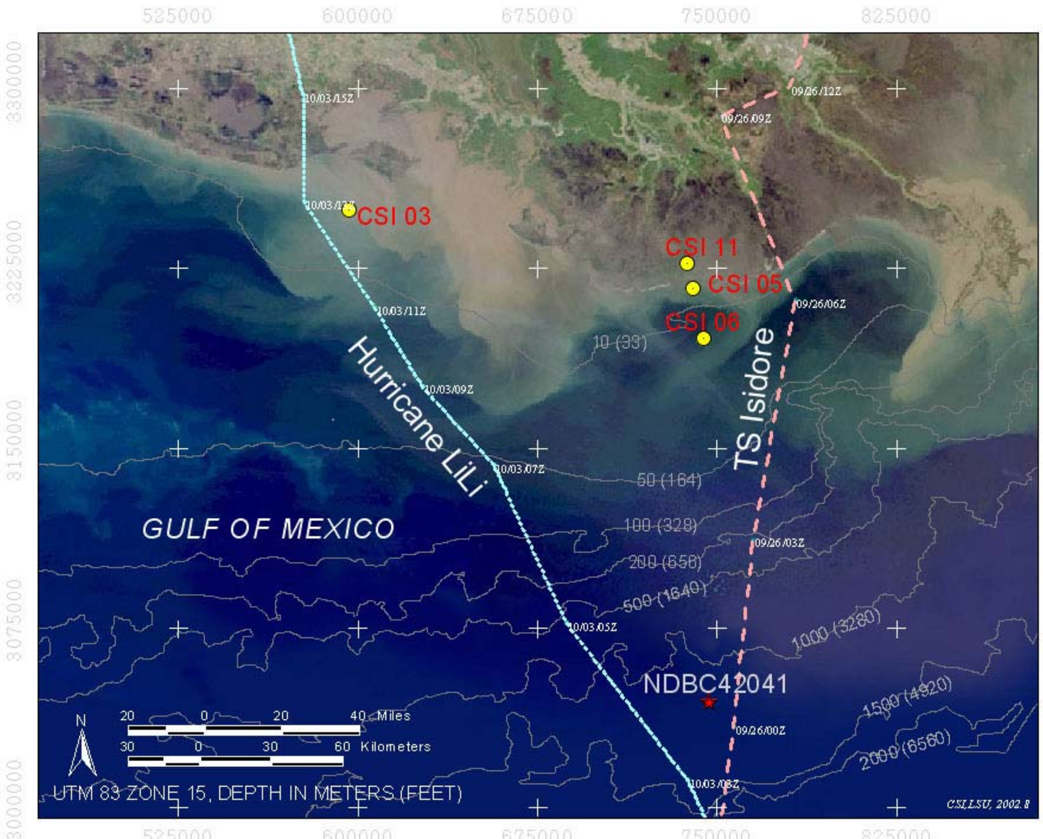


Figure D.4- 2. MODIS image showing the location of various ocean observing stations relative to storm tracks of TS Isidore and Hurricane Lili.

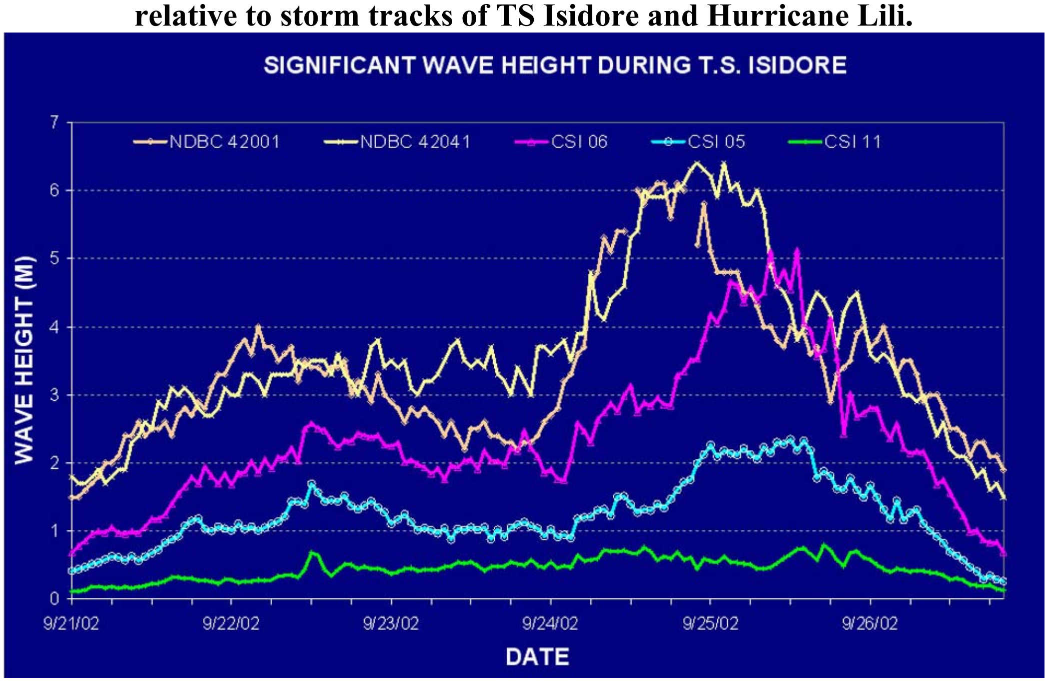
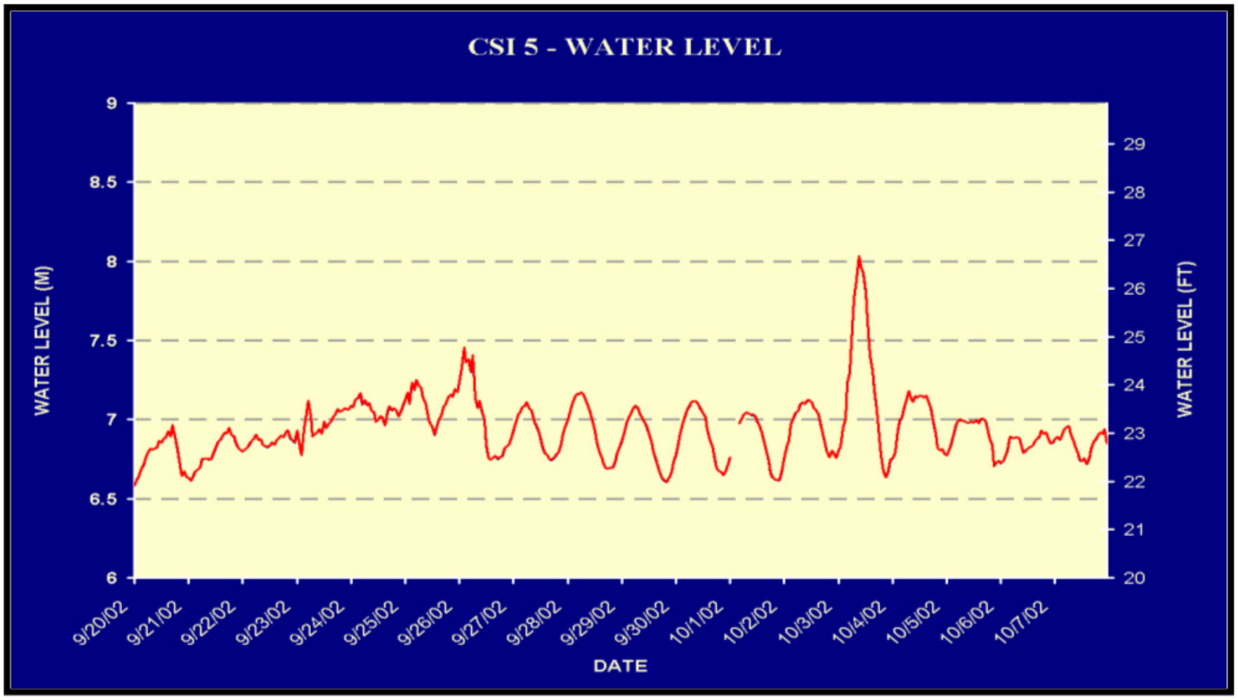


Figure D.4- 3. Time series of significant wave heights (m) at five locations from the central GOM to Terrebonne Bay along the path of TS Isidore.



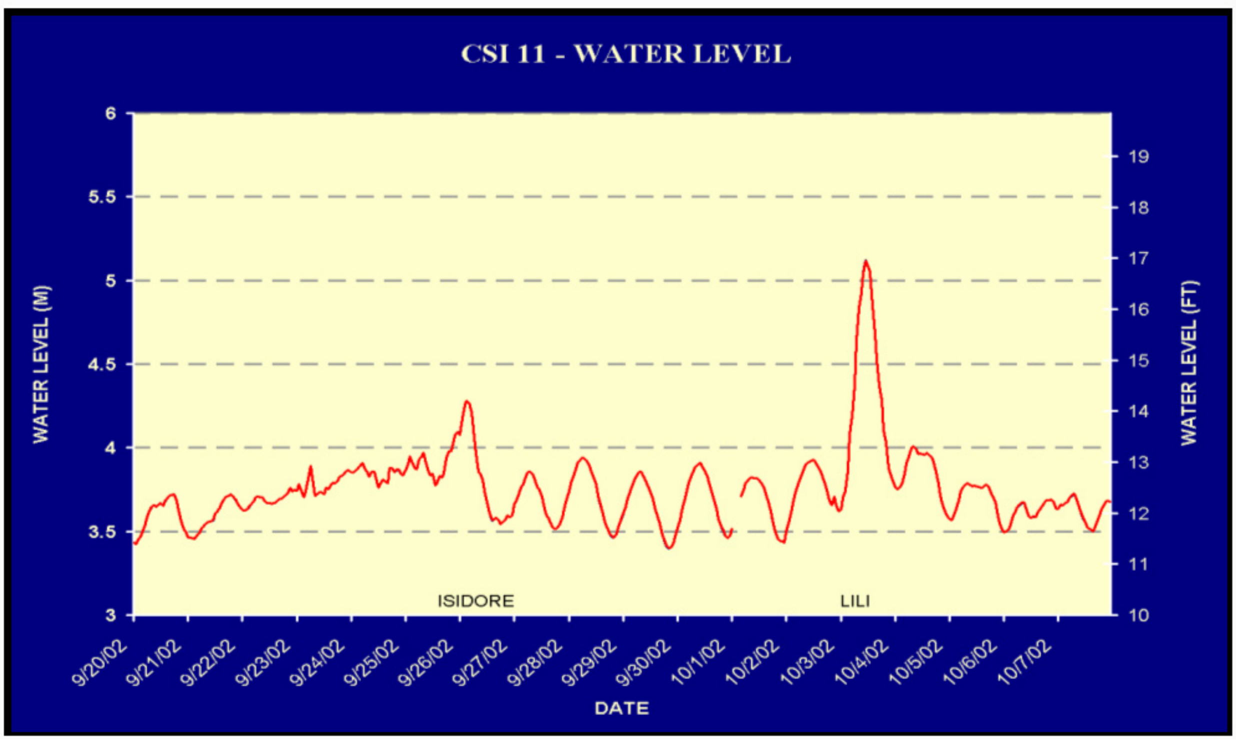
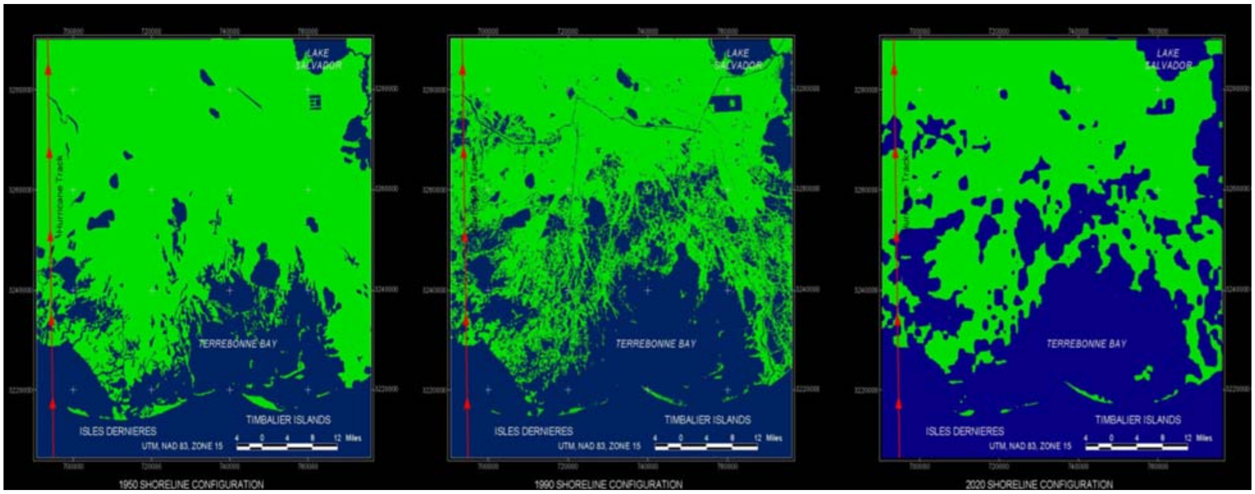


Figure D.4- 4. Water/surge levels during Tropical Storm Isidore and Hurricane Lili measured in shallow water off Timbalier Island (CSI 5) and in Terrebonne Bay (CSI 11).



Study site in the early 1990s where the study site had been reduced to ~0.85 million acres of land, a 24% reduction. Right: Forecast loss of land in the study site by the year 2020 (from Stone et al. 2003).

Figure D.4- 5. Left: Coastal configuration in 1950 where the study site had ~1.09 million acres of land. Middle:

Data indicate that the vast majority of the study site underwent a considerable increase in combined surge and wave height between 1950 and the 1990s when simulating a category 3 hurricane. This is an important period in time in that it represents the actual physical breakdown of the coast, a reduction of some 24% to which the increase in surge and wave height can be directly attributed. Examples of surge and wave heights combined and their relative changes for time period comparison are shown in Figure D.4-s 6 through 8. The data thus provide a highly unique data set demonstrating that the deterioration of coastal south-central Louisiana has likely resulted in an increase in surge and wave height during the 40-year period under study.

It is clearly evident from the comparisons of both surge and wave height presented here that the physical loss of the barrier islands and marsh resulted in a considerable increase in modeled surge levels and wave heights. Although this response is clearly evident on the barrier coast, the composite of waves and surge also show considerably more inundation for the bay marsh shorelines and inland areas in the 1990s scenario, when compared to that of 1950. The forecasted erosion of both barriers and marsh to the year 2020 also supports this conclusion. In Figure D.4- 9 the degree of surface area inundated is presented for both time intervals. In Panel A the area of inundation is plotted against the maximum surge elevation for both time periods. The 1950-1990s scenario, where the curve is above zero, indicates an increase in area impacted by storm surge. Since storm surge is not uniform throughout the study area, incremental surge levels are plotted against acreage inundated. Change associated with surge levels greater than 15 ft (4.6 m) were negligible and not included.

As an example, between 1950 and the early 1990s the acreage impacted by a modeled 7 ft (2.1m) surge increased to 69,000 acres. Similarly, the early 1990s scenario suggests that the acreage impacted by 12 ft (3.7 m) surge levels increased to 49,000 acres. When presented in this fashion, it is readily apparent that on comparing maximum storm surge levels for both scenarios, the loss of barrier islands and marsh results in an increase in maximum surge levels in the study area. For the 1990s-2020 comparison (Panel A) much of the curve shows an increase in acreage to a maximum of 20,000 acres up to the 12 ft (3.7 m) surge level. The 12 and 13 ft (3.7 m and 4 m) surge intervals show a decrease of acreage of up to 15,000 acres (12ft; 3.7 m). It is evident, however, that the vast majority of the study area experienced an increase in the surface area inundated by storm surge.

A similar analysis was performed for significant wave height (Panel B) and the composite of surge and wave height (Panel C). The curve representing significant wave height change and corresponding surface area shows a distinct increase when the 1950 and 1990s scenarios are compared. A peak of a 110,000 acre increase corresponds to a wave height of 6 ft (1.8 m). A comparison of the 1990s and 2020 scenarios shows a similar curve, although the peak increase in inundation is less at 58,000 acres. Finally, the composite of maximum surge and significant wave height illustrate the same trend for both scenarios where virtually all of both curves indicate a distinct increase in area inundated increasing to a maximum of slightly greater than 80,000 acres for the 1950-1990s scenario comparisons and 35,000 acres for the 1990s-2020 comparisons.

The data presented in Panels A, B and C are based on change that occurred between the respective time intervals, 40 and approximately 30 years. In order to normalize the data for this time discrepancy and remove the differential time bias, the data were expressed as a rate of change per year. The data are presented in Panels D, E and F. While the curves take on exactly the same shape, normalizing for the time disparity reduces the difference in magnitude of the surface area change.

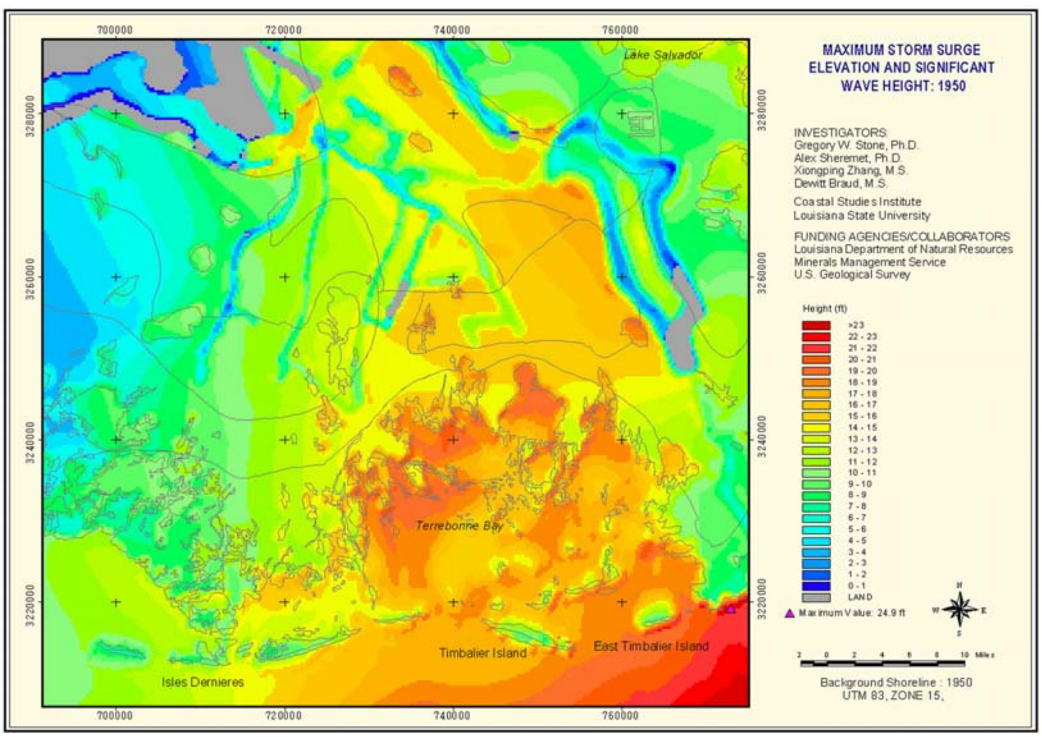


Figure D.4- 6. Distribution of maximum surge elevation and significant wave height across the study site for the 1950 scenario (from Stone et al. 2003).

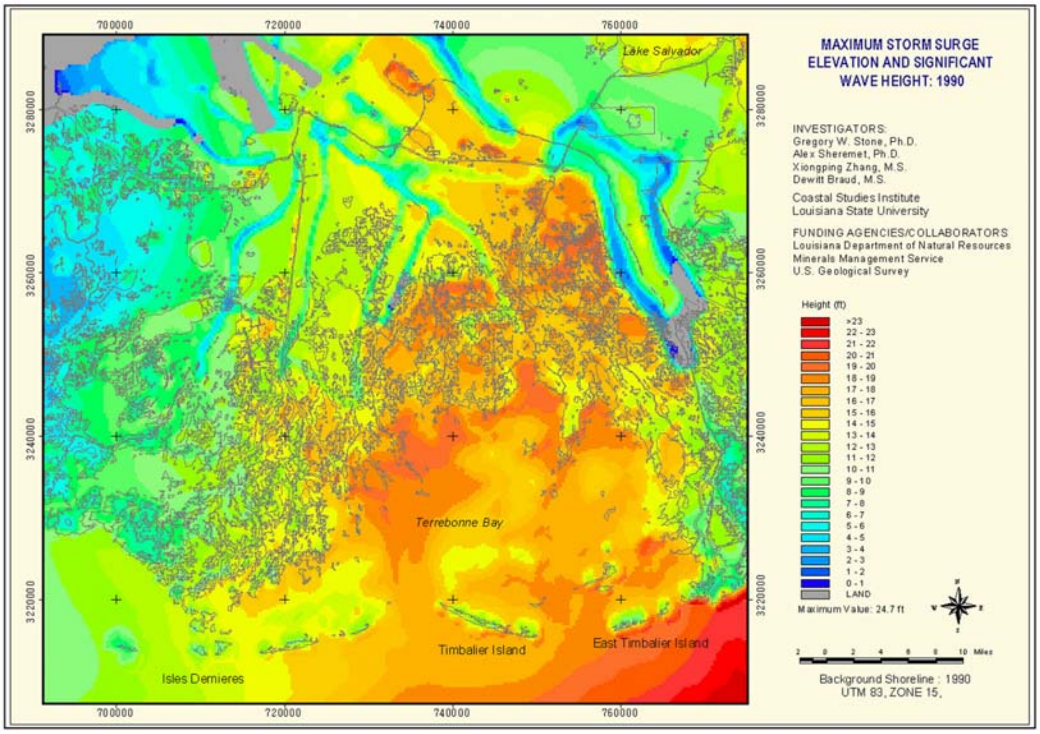


Figure D.4- 7. Maximum storm surge elevation and significant wave height distribution across the study site for the 1990s scenario (from Stone et al. 2003).

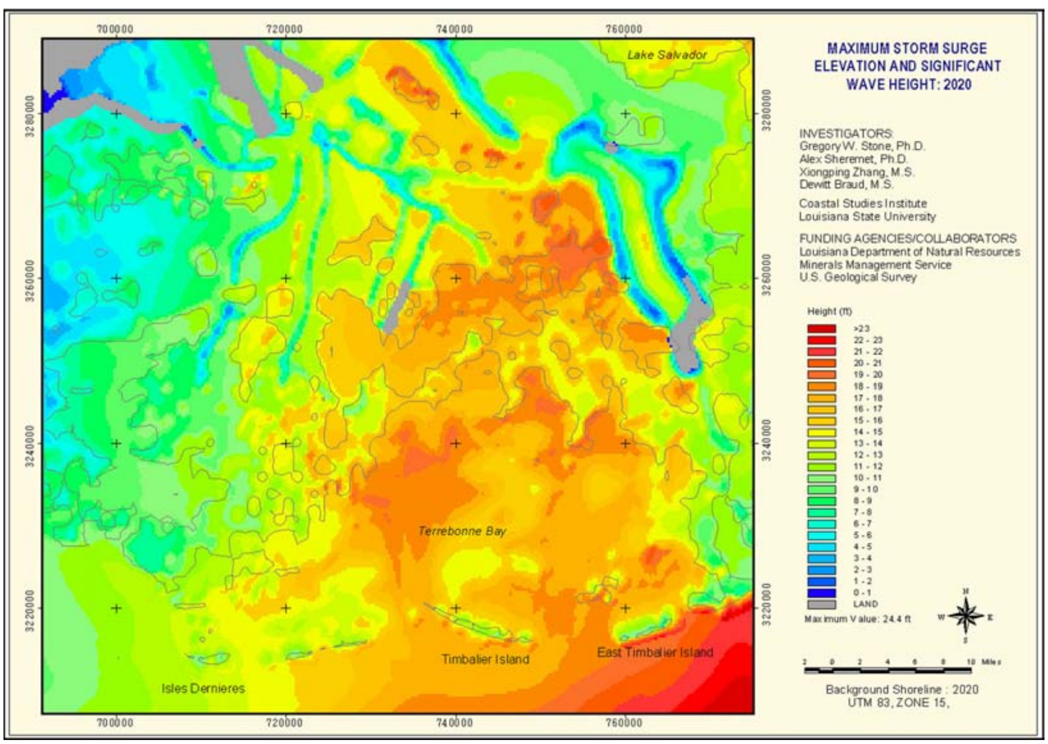


Figure D.4- 8. Maximum storm surge elevation and significant wave height for the study area in the 2020 scenario (from Stone et al. 2003).

4.3 Shell Reefs

4.3.1 Introduction

Until recently, oyster reefs in Atchafalaya Bay and the adjacent coast of the Chenier Plain helped reduce wave energy in those areas. When the reefs were dredged in the 20th Century, an important means of protecting these coastal ecosystems from open marine conditions was lost. Modeling shows increases in wave energy over time with the removal of shell reefs and the gradual change of the bay from semi-protected to open marine conditions.

West of the Isles Dernieres barrier chain, the geology of south-central Louisiana changes considerably. Point Au Fer Island, Marsh Island, and the eastern flank of the Chenier Plain are predominantly Holocene marsh deposits flanking a vast area of swamp bounded by Bayous Teche and Lafourche. The northern flank of the marsh abuts the Pleistocene Terrace (Figure D.4-10). Point Au Fer and Marsh Island are separated by the Atchafalaya Bay and the remnants of what was an extensive area of shoal reefs. West of Southwest Pass, which exchanges waters from the Gulf of Mexico and Vermillion Bay, the geology changes to one of classic chenier ridges backed by extensive marsh deposits (Figure D.4- 10).

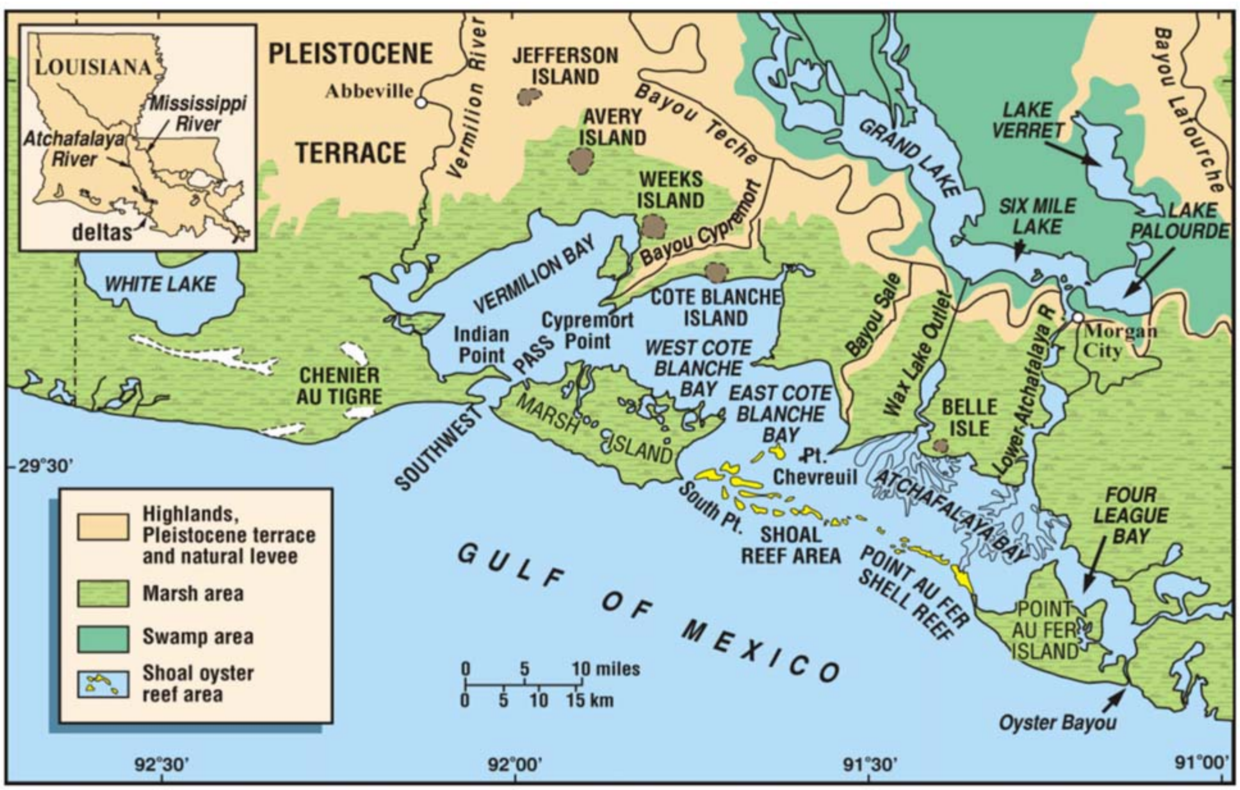


Figure D.4- 10. Map of the study site from Point Au Fer to the eastern flank of the Chenier Plain.

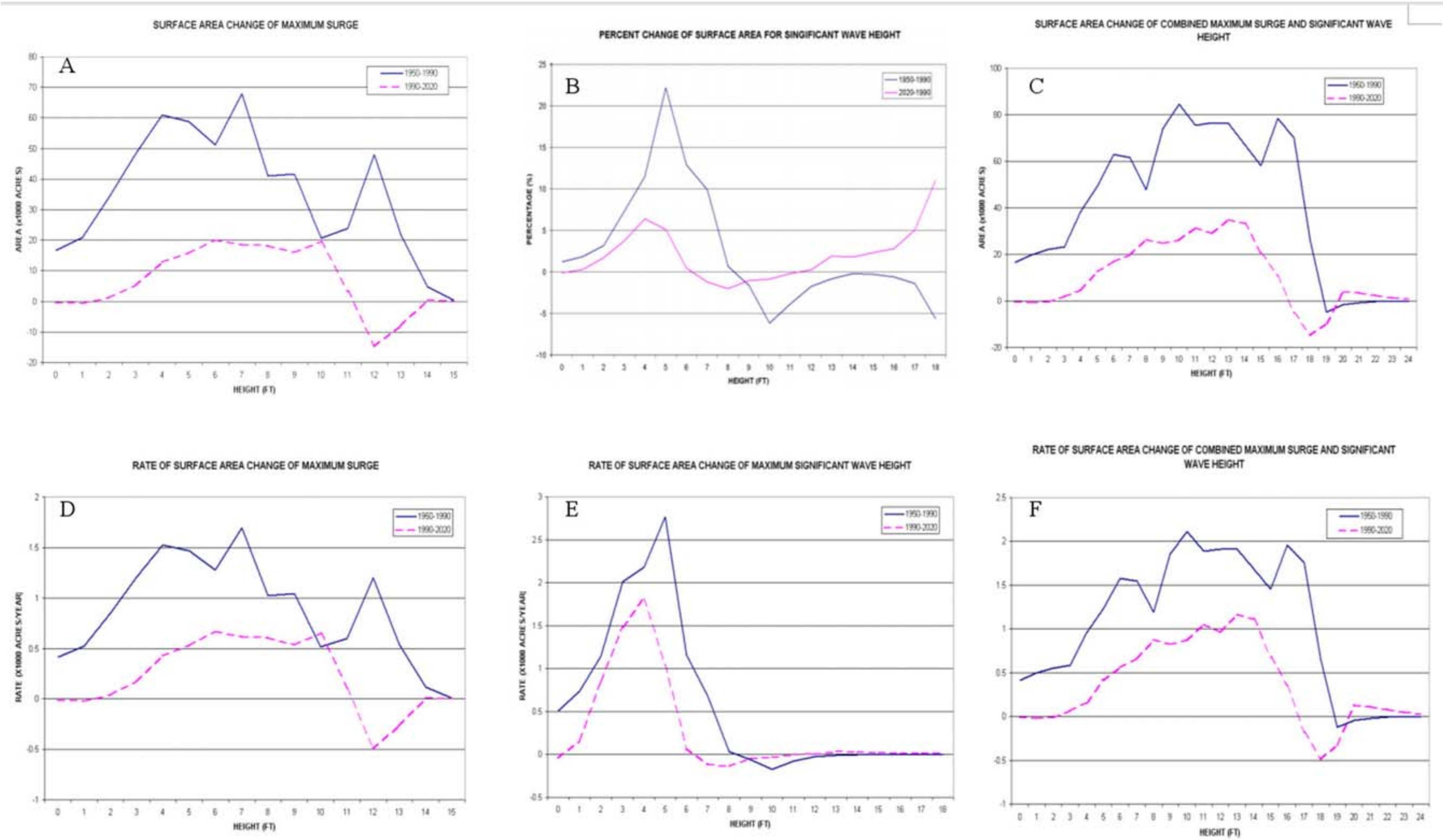


Figure D.4- 9. Surface area change of maximum surge (A), maximum significant wave height (B) and the composite of surge and wave height (C). Rate of surface area change of maximum surge (D), maximum significant wave height (E) and the composite of surge and wave height (F).(from Stone et al. 2003).

4.3.2 Influence of the Atchafalaya River on Coastal Processes

This region is an extremely complicated section of coast due to the influence of the Atchafalaya River and its debouching of fine sediment (silts and clays) into the coastal zone of the Gulf of Mexico (Figure D.4- 11). Subsequent effects of fine grained sediment on the inner shelf are particularly important in determining trends in wave propagation and nearshore wave-current properties. Recent efforts to better understand this system (Roberts et al. 2002; Sheremet and Stone 2003; Stone et al. 2003) will ultimately help improve future management decisions. For example, according to preliminary findings of Sheremet and Stone (2003), numerical models used to calculate wave parameters (e.g. height) for engineering analyses are not likely to reliably predict wave behavior.

Historically, the dynamics of this area have been tied to delta switching events of the Mississippi River. Work carried out along the coast and adjacent mudflats indicate that somewhere between 1946 and 1948, what was initially an erosional coast was becoming stable to progradational (Morgan et al. 1953; van Lopik 1955; Morgan and Larimore 1957; and Morgan 1963). This significant change in coastal response affected some 25 km of the eastern flank of the Chenier Plain and was attributed to the persistent capture of Mississippi River discharge by the Atchafalaya distributary. The Atchafalaya, while active since the 1500s, is prevented from capturing the Mississippi River by a control structure built in 1963 and maintained by the U.S. Army Corps of Engineers (USACE). Nevertheless, the Atchafalaya still carries approximately 84 million metric tons of sediment onto the shallow shelf annually (Wells and Kemp 1981).

The tidal regime along the coast is microtidal, with an average tidal range of between 0.4 and 0.6 m. Barring tropical cyclones, wave energy conditions are generally storm driven and highly responsive to the passage of winter cold fronts (Roberts et al. 1989; Huh et al. 2001). In Figure D.4- 42, the impacts of frontal passage along this coast are readily apparent where wave energy peaks are in phase with peak sustained wind speeds. These data were recorded at a WAVCIS station south of Marsh Island at the 5 m isobath. Storm waves typically range between 0.5 and 1.0 m during winter storms associated with fronts, but the waves are significantly attenuated (Stone and Sheremet 2003). In Figure D.4- 16, a comparison of wave height at CSI 3 and CSI 5 about 150 km to the east shows the attenuation effect clearly where wave heights at the andier site are typically higher during the same storm event.

(image obtained from Earth Scan Lab, Coastal Studies Institute, Louisiana State University).

Figure D.4- 11. Terra Modis image of Atchafalaya Bay showing the infusion of fine grained sediment into the bay and Gulf of Mexico

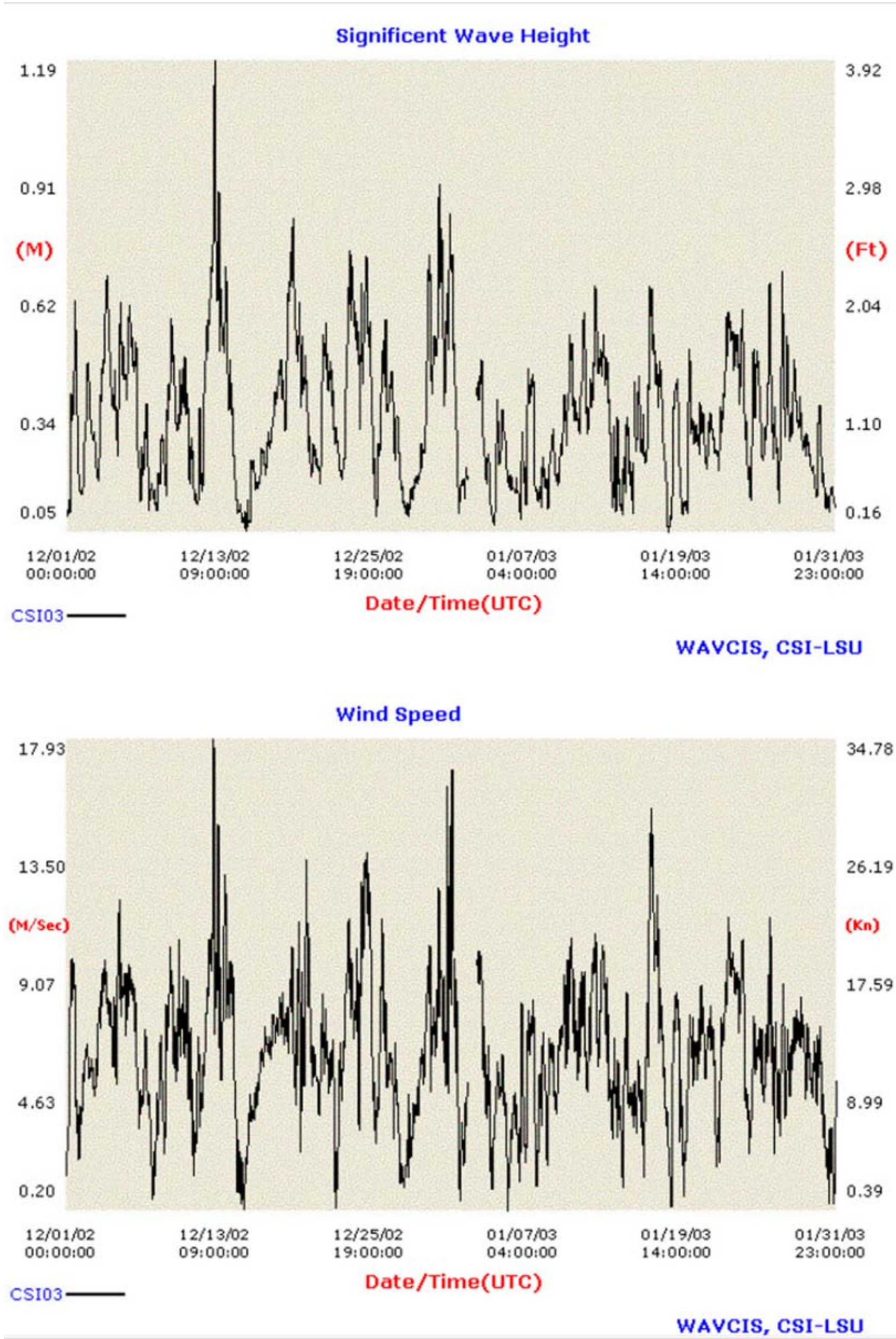


Figure D.4- 12. Upper: Time series of significant wave height (12/02-01/03) at a WAVCIS station (CSI 3) located on the 5 m isobath off Marsh Island. Lower: Time series of sustained wind speed recorded at CSI 3. Note the correlation of peak wave energy with periods of highest sustained winds.

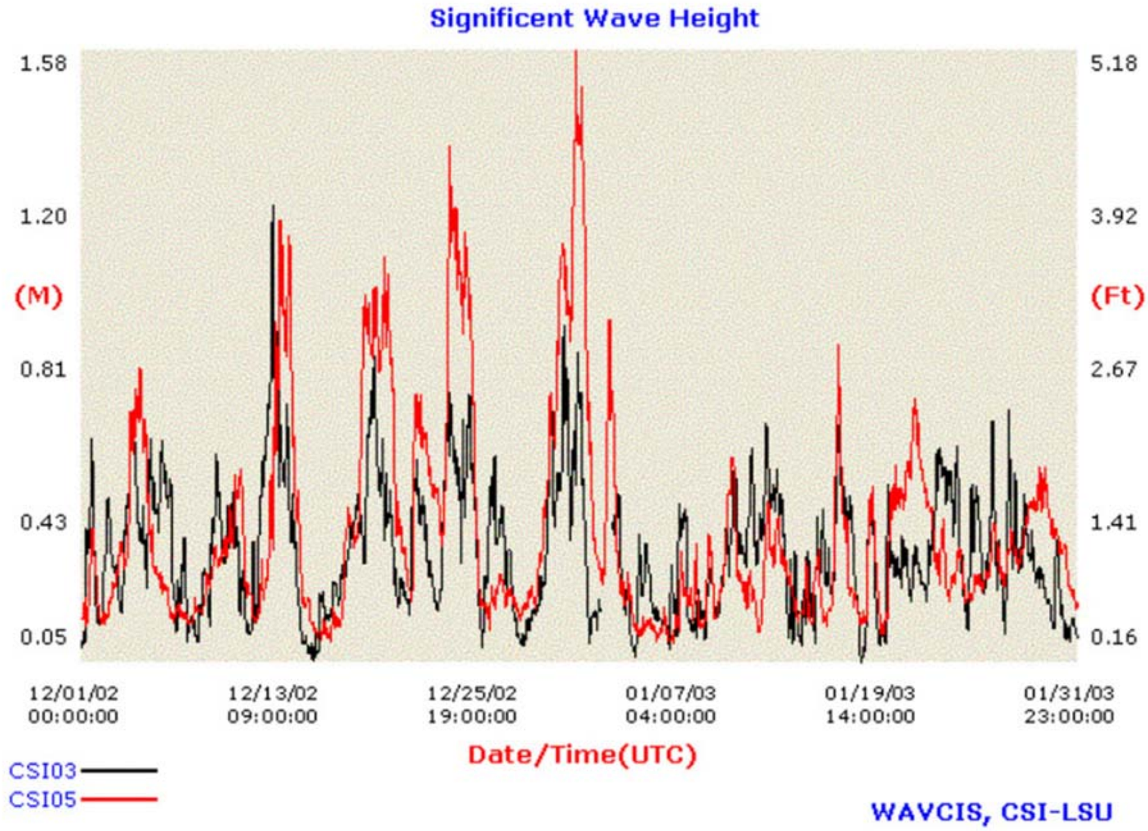


Figure D.4- 13. Comparison of significant wave height at CSI 3 and CSI 5 where 3 is located in an offshore area dominated by mud, and 5 is more sandy.

The apparent wave attenuation, or damping effect, plays an integral role in mud flat accretion along the eastern chenier complex. The paradigm of storms generally resulting in coastal erosion does not necessarily apply to this location. To the contrary; Wells (1983), Kemp (1986), Roberts et al. (1989), and Huh et al. (2001) have all documented the importance of storm waves in mud flat accretion along the beach during winter cold fronts. Pre-frontal events typically involve lower frequency waves generated by strong winds from the south resulting in setup along the coast and deposition of mud on the beach. Post-frontal winds blow from the north and result in rapid setdown of waves and water levels. This, in turn, creates mud flat exposure. Huh (1991) describes this mud as gelatinous but only for a short period of time. Rapid air drying results in the formation of polygonal blocks some 18 cm (0.6 ft) thick. The occurrence of cold fronts along the area ranges from 20 to 40 per year (Chaney 1999), implying the significance of these events over longer time scales. Mud transported onshore from the continental shelf can also occur during hurricanes (e.g. Lili in 2002; Stone et al. 2003). However the frequency of these events when compared to frontal passage is significantly less (Muller and Stone 2002). Work by Morgan and Larimore (1957), also summarized in Stone and McBride (1998), showed that while the Chenier Plain coast was eroding historically at a rate 5.6 m/yr (18.5 ft/yr), the area at Chenier Au Tigre was accreting at approximately 4 m/yr (13.2 ft/yr). In the late 1980s and early 1990s Huh et al. (1991, 2001) documented progradation rates as high as 50 m/yr (16 ft/yr). It is now understood why this localized phenomenon is occurring.

Beach sediments characteristic of the area range from shell deposits with a fine grained sand matrix to shelly sand deposits. The sources of this sediment are the Atchafalaya and Mississippi Rivers. Previously deposited delta front sands in the Trinity/Tiger Shoal area off Marsh Island may have been an important source for sandier sections of the modern beach. Reworking of this material with an admixture of locally supplied shells has formed a complex pattern of chenier ridges (Taylor 1996).

4.3.3 Shell Reef Interaction with Wave Behavior

An important, but seldom discussed phenomenon is the effect of oyster reefs in this area on local coastal processes. Figure D.4- 14 shows an historic bathymetric map of the inner shelf and Atchafalaya Bay, including reef location and spatial extent. In Figure D.4- 15, a map of the area is presented showing significantly fewer reefs. Throughout the 20th Century a considerable number of the reefs were dredged for commercial purposes. As a result, the bay and adjacent shorelines began experiencing a significant transformation from a once low energy, protected environment, to a higher energy, open marine system. This is portrayed in Figure D.4-s 16 and 17 where the wave energy (height) distribution is presented based on the output from a spectral wave model (SWAN). Using fair-weather deep water wave conditions whereby the input boundary conditions were wave height equals 1m (3.3 ft), period 6 seconds, and wave direction was to the north-northeast, the effects of the shell reefs on the wave field is very apparent.

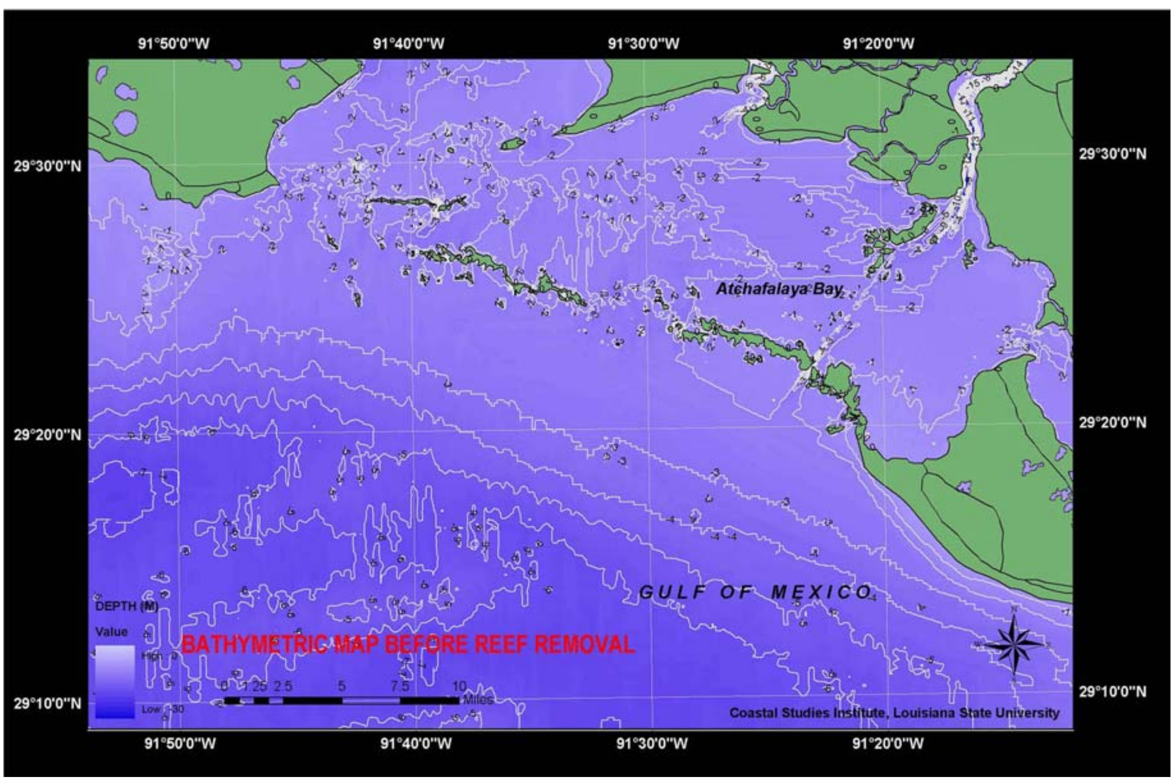


Figure D.4- 14. Bathymetric map of the Atchafalaya Bay and inner shelf prior to the gradual dredging of oyster reefs.

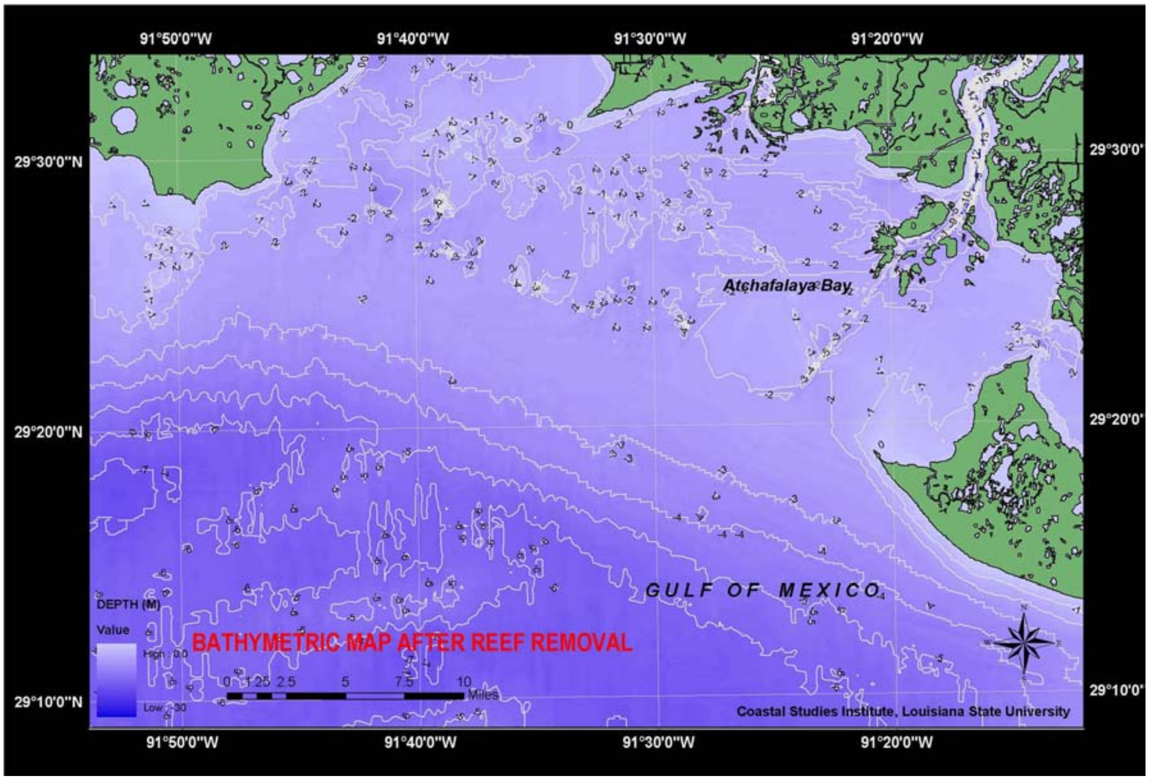


Figure D.4- 15. Bathymetric map of the inner shelf and Atchafalaya Bay area after removal of virtually all oyster reefs for commercial use.

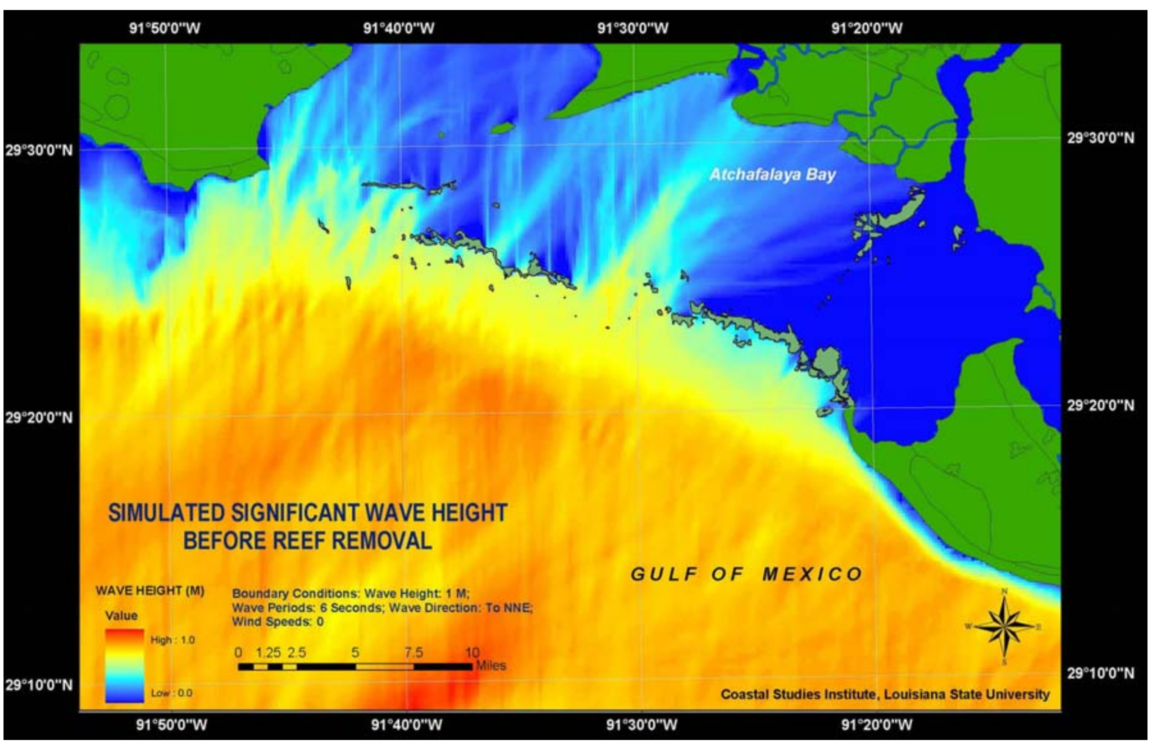


Figure D.4- 16. Distribution of wave height modeled using SWAN for conditions prior to oyster reef removal. Conditions are indicative of fair-weather waves.

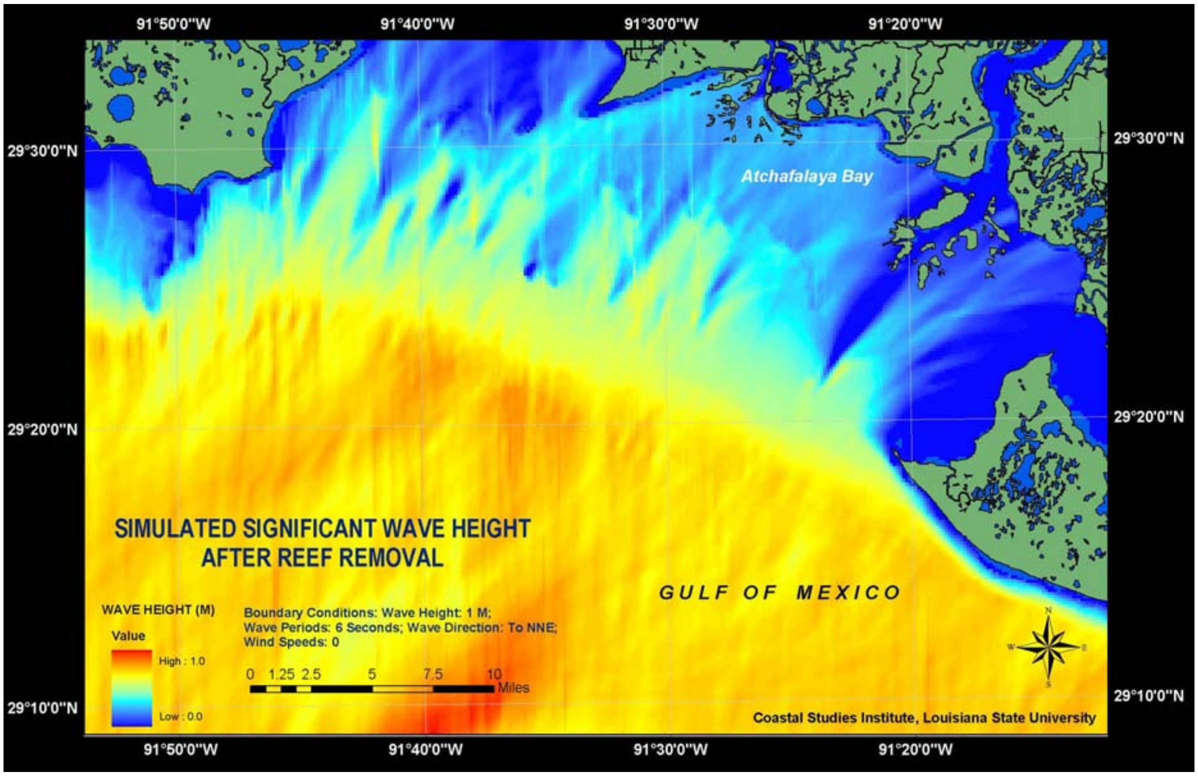


Figure D.4- 17. Distribution of wave height modeled using SWAN for conditions after oyster reef removal. Conditions are indicative of fair-weather waves.

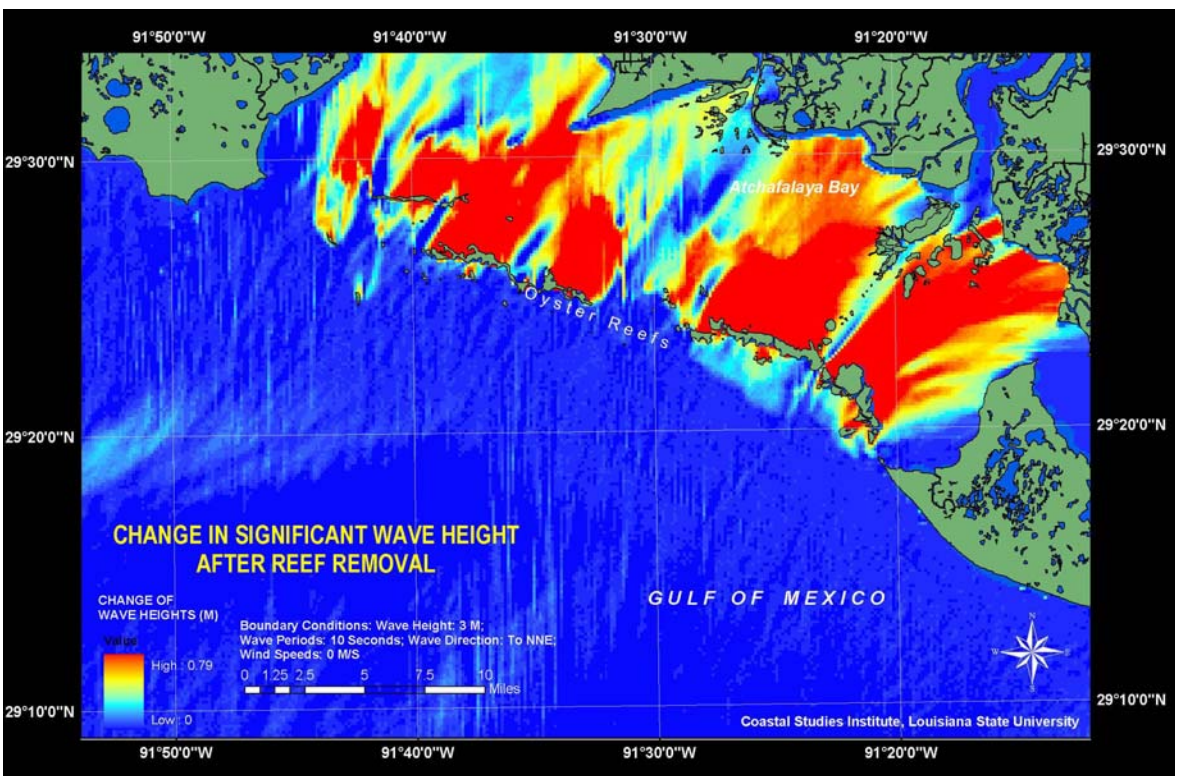


Figure D.4- 18. Difference in wave height due to oyster shell reef removal.

Historically, the Atchafalaya and Wax Lake Deltas and adjacent shorelines were very well protected from wave impacts and potential erosion. The degree of protection no longer afforded by the reefs is evident in Figure D.4- 18. The maximum increase in wave height due to oyster reef removal is shown in red and is as high as 0.74 m for fair-weather waves. Although not presented here, additional simulations suggested that increasing wave heights associated with storms resulted in an increase in wave energy after reef removal.

Although a considerable amount of wave energy dissipation occurs along the inner shelf in this area (Sheremet and Stone 2003), historically, the oyster reefs controlled wave processes and mitigated the wave field in Atchafalaya Bay and the adjacent coast. The bay system has transformed into an open marine, higher energy wave-dominated system with time, a phenomenon that significantly impacts future restoration efforts in the area. In addition, the influence of fluid mud on the shelf adjacent to this coast presents significant challenges to scientists and engineers active in numerical modeling of hydrodynamic coastal processes. As presented by Sheremet and Stone (in press), state-of-the-art numerical wave models currently lack the capability to accurately simulate wave propagation across this muddy shelf.